The First ILRS Laser Transponder Mission: Laser Ranging to NASA's Lunar Reconnaissance Orbiter (LRO)

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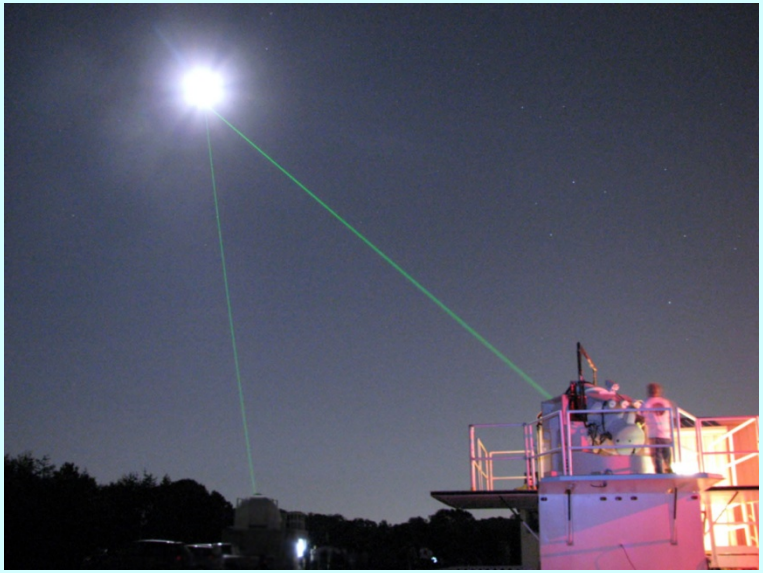
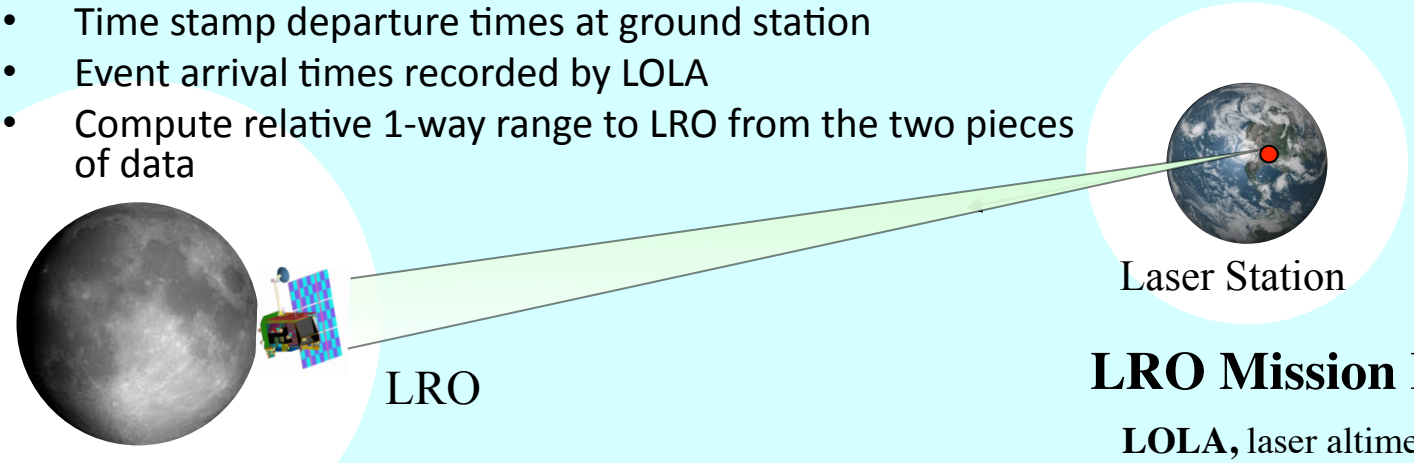
Abstract:
Since the launch in June 2009 of LRO, Laser Ranging (LR) to LRO has been a huge success, accumulating over 1000 hours of one-way laser ranging data. The participation of the global community of stations has been a very large part of that success. Ten stations around the world contribute to the ranging data, including NASA's Next Generation Satellite Laser Ranging (NGSLR) system, McDonald Laser Ranging System, many of the NASA MOBLAS systems, and four European stations. A brief overview of the LRO-LR technique will be followed by a summary of the results to date. Details of the data since launch will be given in a related poster.



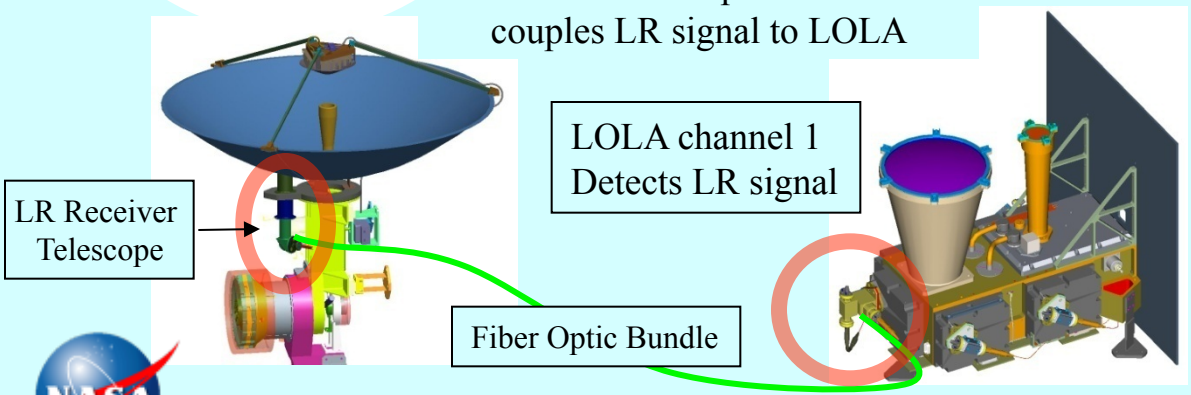
Lunar Reconnaissance Orbiter (LRO) – Laser Ranging (LR) Overview

Sub-network of ILRS supports LRO for one-way laser ranging

- Transmit 532 nm laser pulses at =< 28Hz to LRO
- Time stamp departure times at ground station
- Event arrival times recorded by LOLA
- Compute relative 1-way range to LRO from the two pieces of data



Receiver telescope on HGAS couples LR signal to LOLA



LRO Mission Includes:

LOLA, laser altimeter

LROC, camera

LAMP, Lyman alpha telescope

LEND, neutron detector

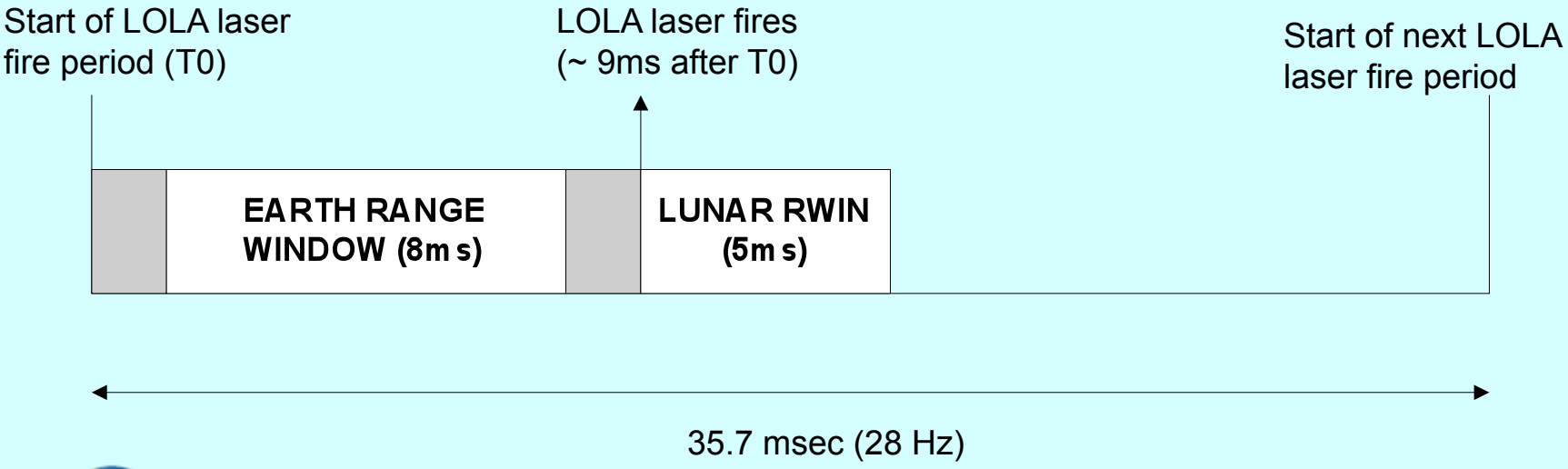
DIVINER, thermal radiometer

CRATER, cosmic ray detector

mini-RF, radar tech demo

One LOLA Detector does both Earth and Lunar

- Two range windows in one detector: fixed 8 msec earth and up to 5 msec lunar.
- Range to LRO changes ~ 5-10 ms over an hour's visibility.
- Need to either synchronize the ground laser fires to LOLA to ensure pulses land in every Earth Window, or fire asynchronously to LOLA (eg 10Hz).



Real-time Feedback from Spacecraft

- Website information constructed at LOLA SOC and hosted on CDDIS.

- Delay from “real-time” is nominally between 10 – 30 seconds, although it can occasionally be minutes delayed.

- Stations can use display to determine if their fires are being detected at LRO/ LOLA, and where their pulses are falling in the Earth Window.

- Asynchronous stations use the website to adjust angular biases.

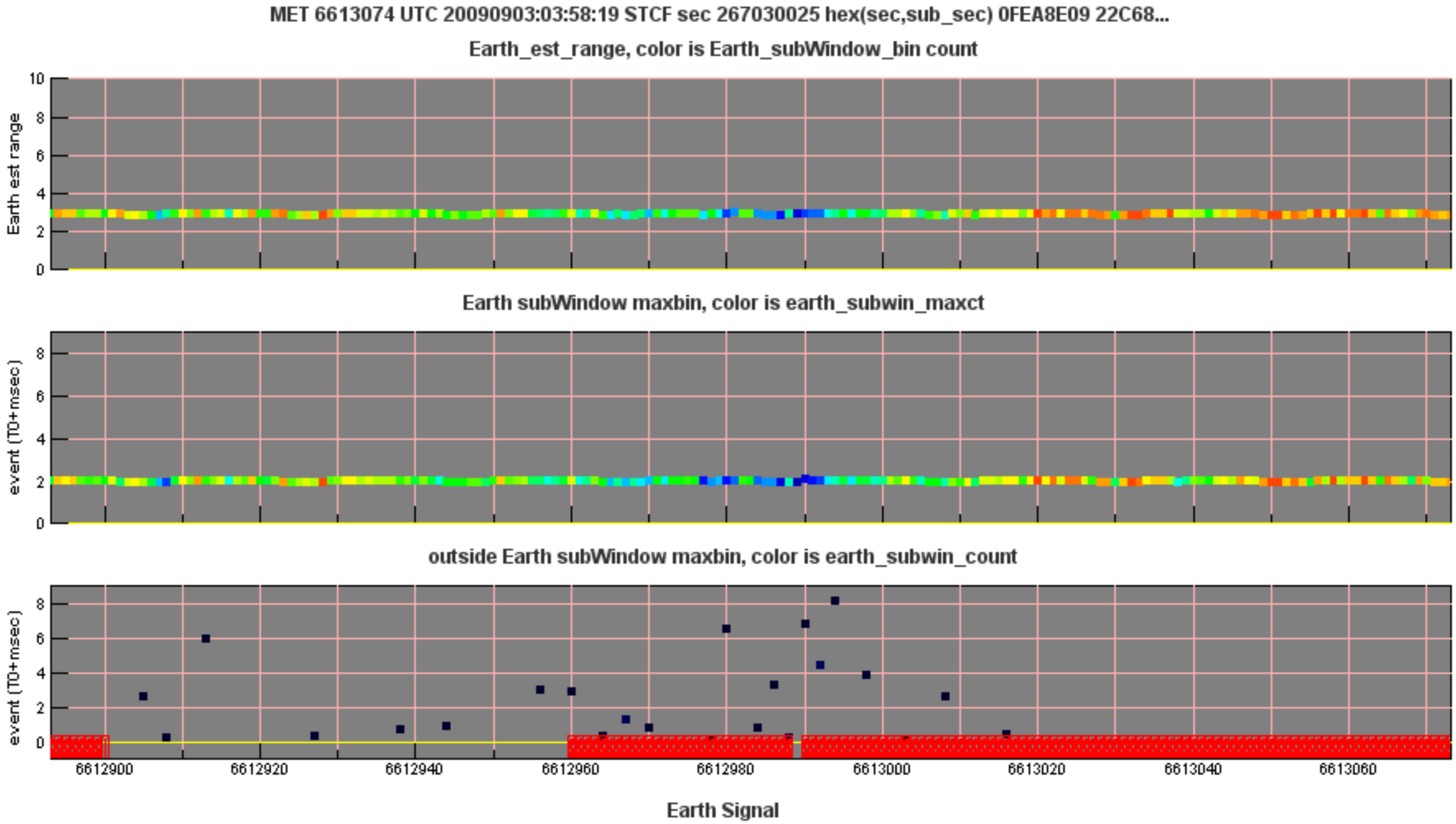
- Synchronous stations use website to modify their fire times as desired:

  - to move their returns earlier in LOLA Earth Window (pulse arrivals earlier in the window have a higher probability of detection because this is a single stop receiver),

  - or later, if ranging simultaneously with another station.

  - to “scan” if LRO/LOLA is not detecting their pulses

Real-time telemetry website



NGSLR Data

Data from 1 second LOLA H/K packets

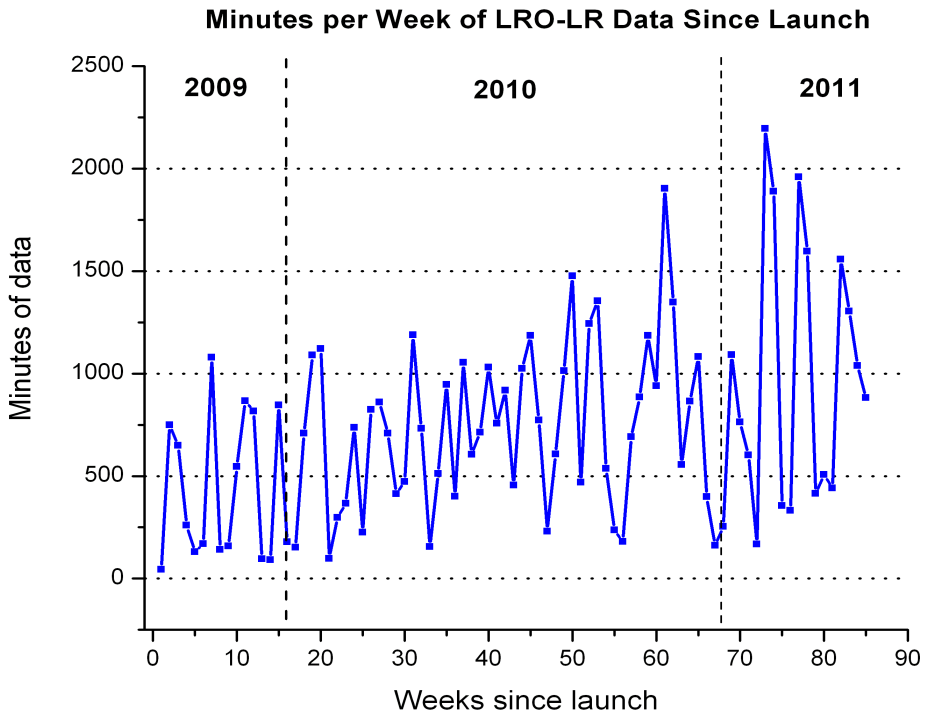
Stations Supporting LR

Station	Location	Synch to LOLA?	Firerate (Hz)	Max # / sec in LOLA window	Expected energy at LRO (fJ / sqcm)	Station Frequency Source	Date of first successful ranging to LRO	LR Status
NGSLR	Maryland, US	Yes	28	28	1 to 5	Maser (18-Oct-2010)	30-Jun-2009	Operational
MLRS, McDonald	Texas, US	No	10	2 to 4	1 to 10	Cesium	02-Jul-2009	Operational
MOBLAS-7, Greenbelt	Maryland, US	No	10	2 to 4	1 to 3	Cesium	02-Jul-2009	Engineering testbed
Herstmonceux	Great Britain	Yes	14	14	1 to 3	Maser (13-May-2010)	13-Jul-2009	Operational
Zimmerwald	Switzerland	Yes	14	14	1 to 3	Ovenized crystal oscillator	20-Jul-2009	Operational
Wettzell	Germany	No	7	7	1 to 10	Cesium	30-Oct-2009	Operational
MOBLAS-6, Hartebeesthoek	South Africa	No	10	2 to 4	1 to 3	Maser	05-Dec-2009	Operational
MOBLAS-5, Yarragadee	Australia	No	10	2 to 4	1 to 3	Maser (14-May-2010)	25-Jan-2010	Operational
MOBLAS-4, Monument Peak	California, US	No	10	2 to 4	1 to 3	GPS steered Rubidum	03-Feb-2010	Operational
Grasse/MEO	France	No	10	2 to 4	1 to 10	Cesium	18-May-2010	Operational

This information and more can be found at: http://lrolr.gsfc.nasa.gov

International Laser Ranging Service

Summary of LR Data



Total LR data from all stations (7 May 2011): 62074 mins = 1078 hrs

FIRSTS

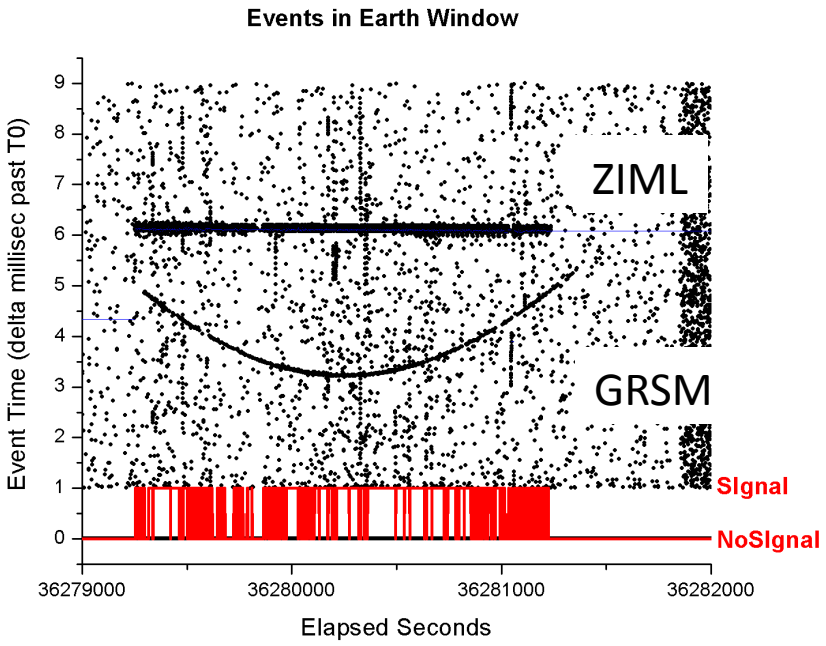
- **Ranging (success on 1st attempt): 30Jun2009 (GO1L)**
- **3-way simultaneous: 01Nov2010 (GO1L,MDOL,MONL)**
- **4-way simultaneous: 11Mar2011 (GO1L,GODL,MDOL,MONL)**
- **Lasercom preliminary test: 10May2011 (GO1L)**

	GO1L	GODL	MDOL	HERL	ZIML	WETL	HARL	YARL	MONL	GRSM
# mins	28334	2524	8203	776	533	66	341	11038	9192	1067
fraction	0.456	0.041	0.132	0.013	0.009	0.001	0.005	0.178	0.148	0.017

International Laser Ranging Service

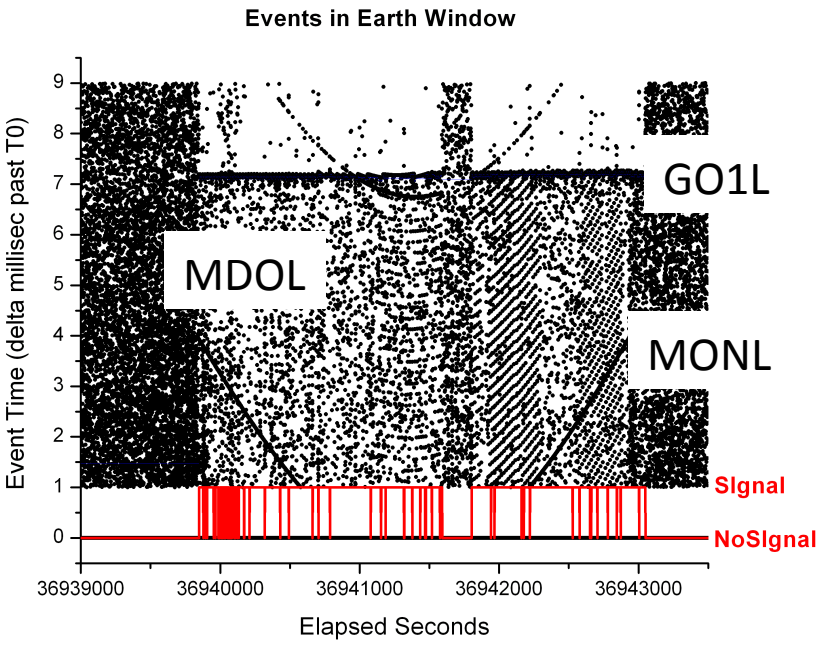
Ranging Data in LOLA EarthWindow

ZIML, GRSM: (8064) 6 Apr 13:28Z



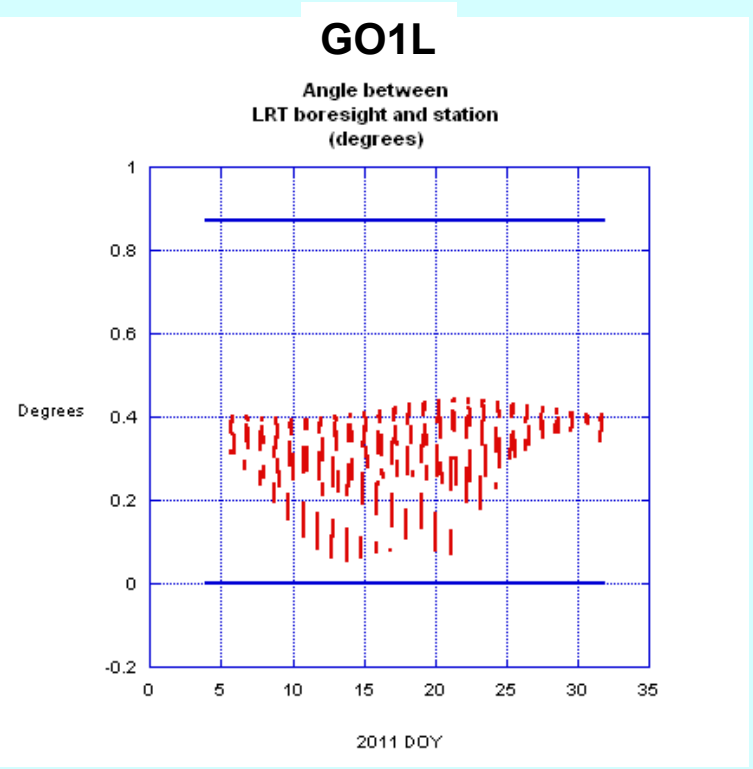
2-way simultaneous in 2011

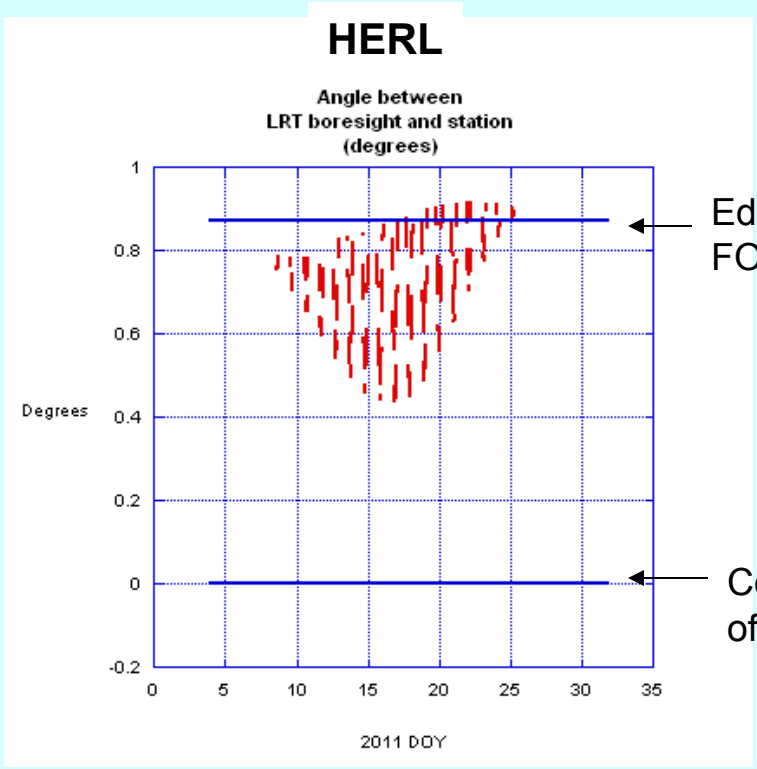
GO1L,MONL,MDOL: (8161/8162) 14 Apr 05:01Z



3-way simultaneous in 2011

Putting Laser Pulses in the LR RFOV





-Red lines represent location of pulses in RFOV for passes where LRO is visible to station above their min elevation limit (normally 20 deg).

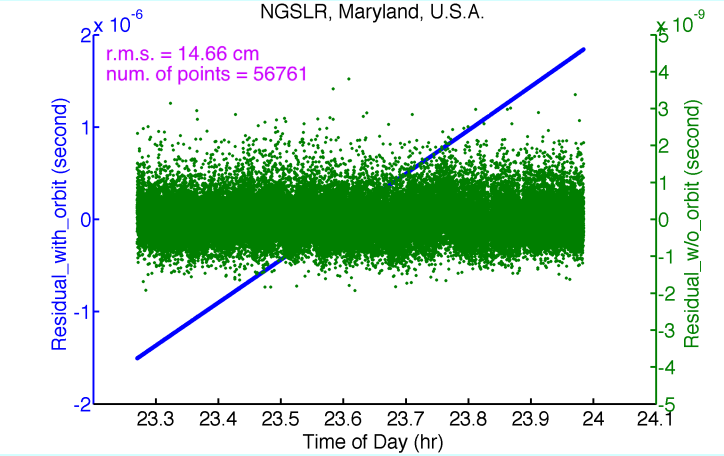
- Blue lines are limits on RFOV. Bottom line is center, top is edge of FOV.

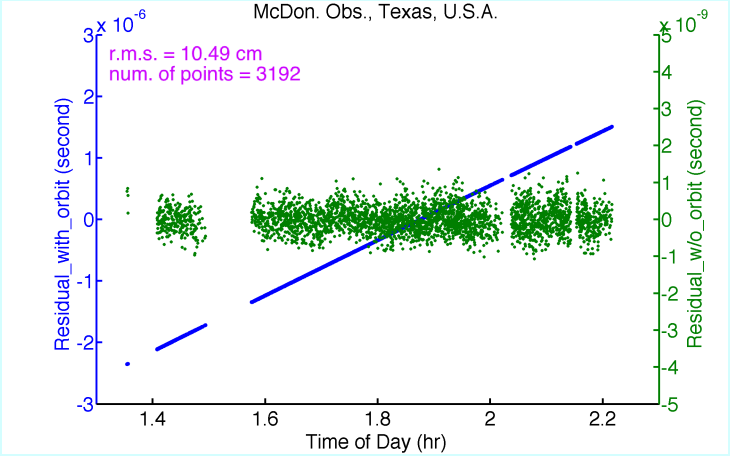
- High Gain Antenna (HGA) pointing accuracy is nominally 0.1 deg, so pointing errors could easily remove many of HERL's passes.

See LRO-LR poster for all stations

Science Results

- LR data used to determine onboard clock drift rate and aging.
- Work in progress for use in generating a more accurate LRO orbit.
- Geometric solution for spacecraft position in progress (with 3-way LR).
- Plan in works to use LR for Time Transfer between stations.

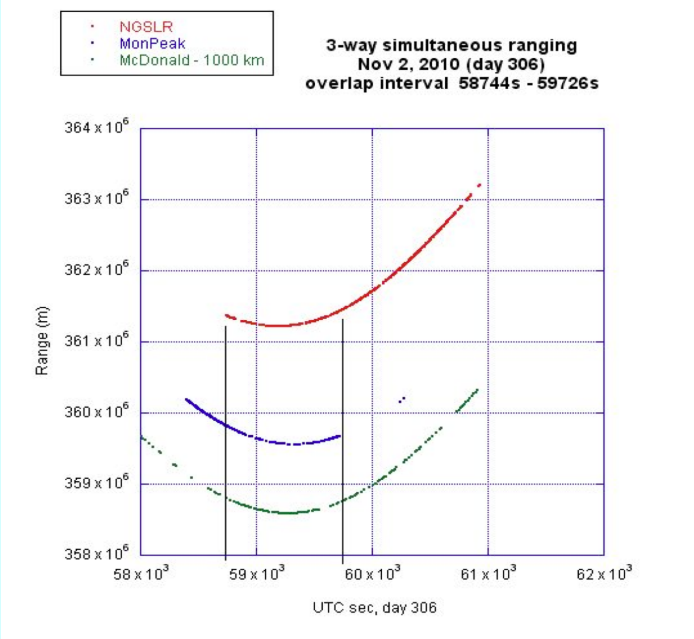


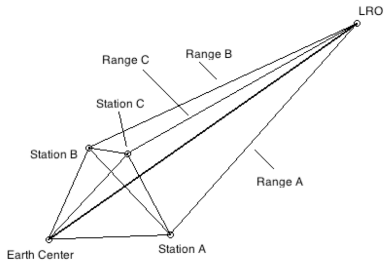


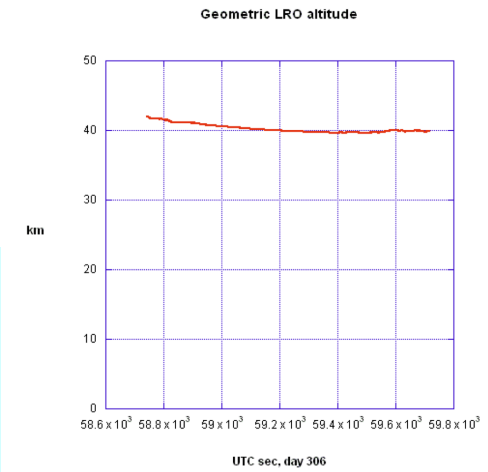
See LRO-LR poster for all stations

Laser Navigation Demonstration

Geometric Solution for Spacecraft Position using 3-way simultaneous LR







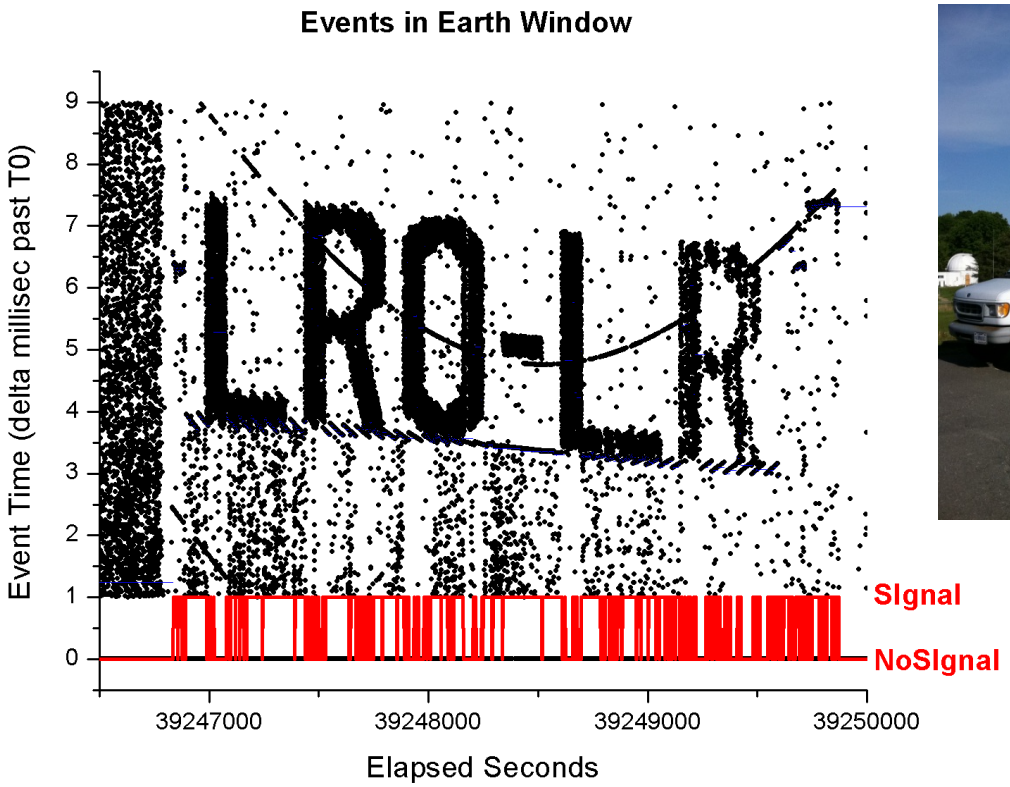
-NGSLR, McDonald Obs., and Monument Peak all ranged to LRO on same pass on 2 Nov 2010.

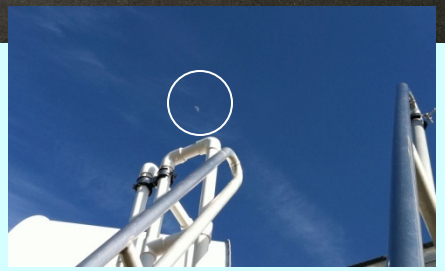
- A geometric solution was then obtained to determine the location of the LRO in 3 dimensions from the knowledge of the station positions and the ranges.

Accuracy of solution using this baseline:
- range ~0.5 meters
- cross-range RA direction ~ 50 meters
- cross-range Dec direction ~ 350 meters (due to weak north-south baseline).

If we had 6000km baselines we would get 5 meters in the cross-range directions (Ra/Dec) and about 0.5 meters in range.

Lasercom over LR

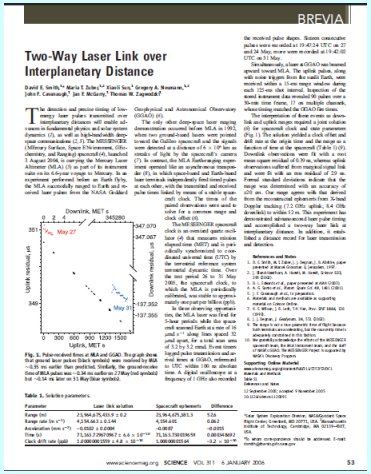




-Preliminary lasercom experiment performed on 10 May 2011 from NGSLR by Xiaoli Sun, Dave Skillman, et al.

- NGSLR wrote the words “LRO-LR” in LOLA Earth Window. MOBLAS-7 is the parabolic curve in the plot.

Two-Way Asynchronous Laser Transponder Ranging from NASA's 1.2 m Telescope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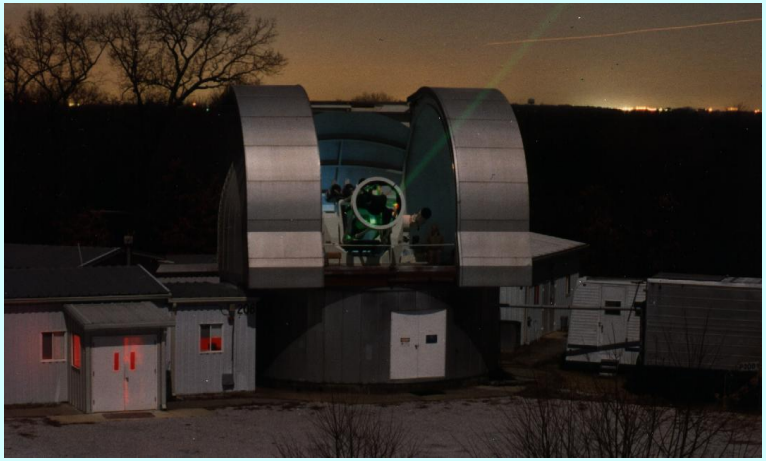
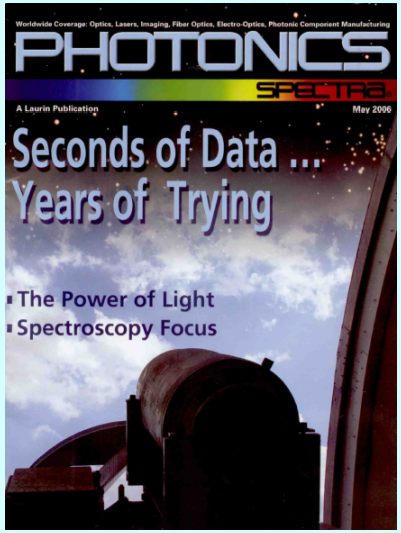
Two-Way Laser Link over Interplanetary Distance





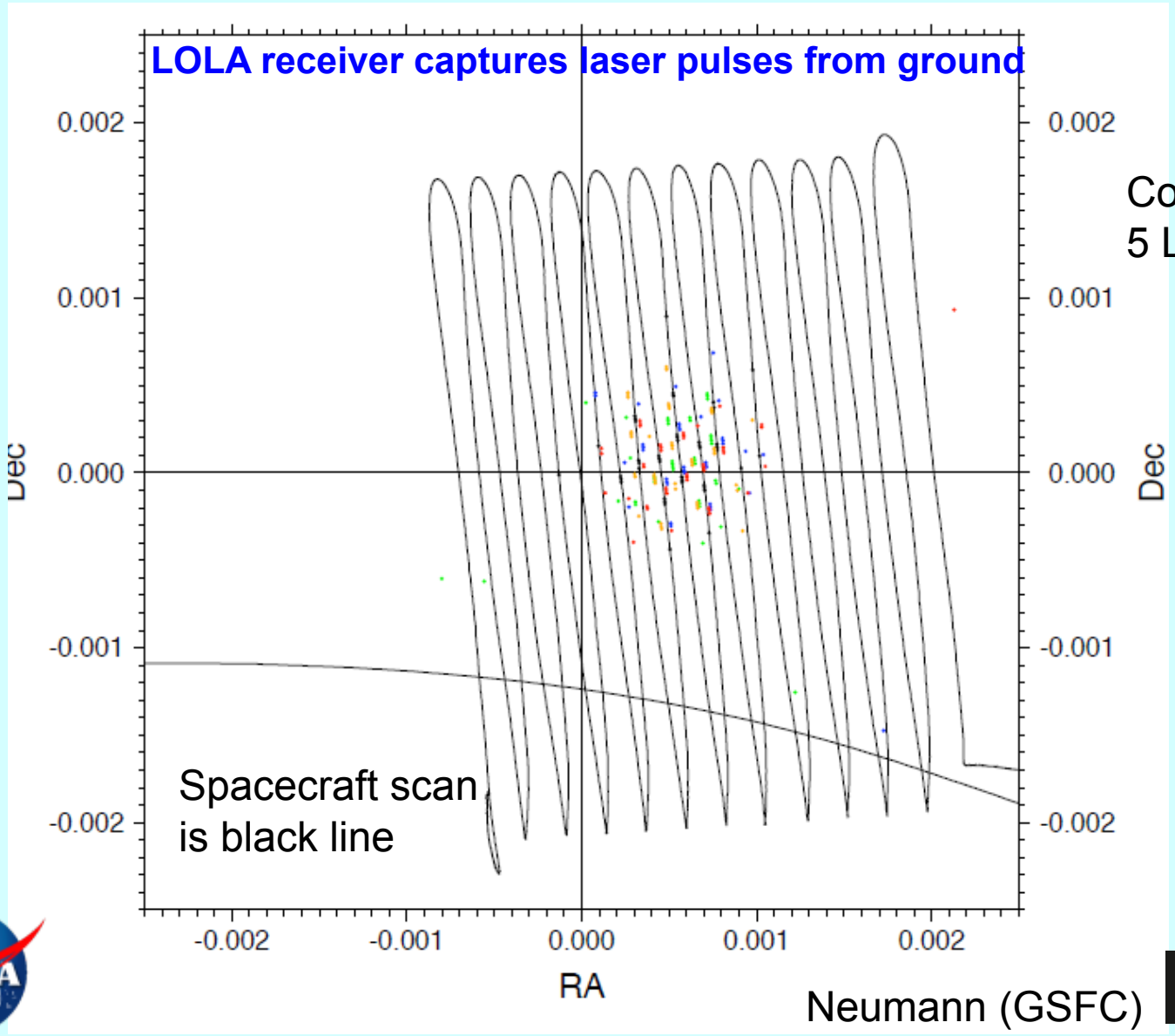
Multi-user arcsecond precision tracking telescope at the Goddard Geophysical and Astronomical Observatory (GGAO).

- **Has supported many successful experiments including in 2005:**
  - **2-way ranging to Mercury Laser Altimeter (MLA) on MESSENGER (24 Mkm), and**
  - **1-way ranging to Mars Orbiter Laser Altimeter (MOLA) on Mars Global Surveyor (orbiting Mars at 80 Mkm).**
- **Successful on-orbit calibration of LOLA (2-way ranging) in 2009: 8/25, 9/13, 9/14.**

Ground Team Lead for all experiments was Tom Zagwodzki (NASA/GSFC)

LOLA 2-Way Ranging: Sep 13 2009

Plot of LOLA received events on scan location

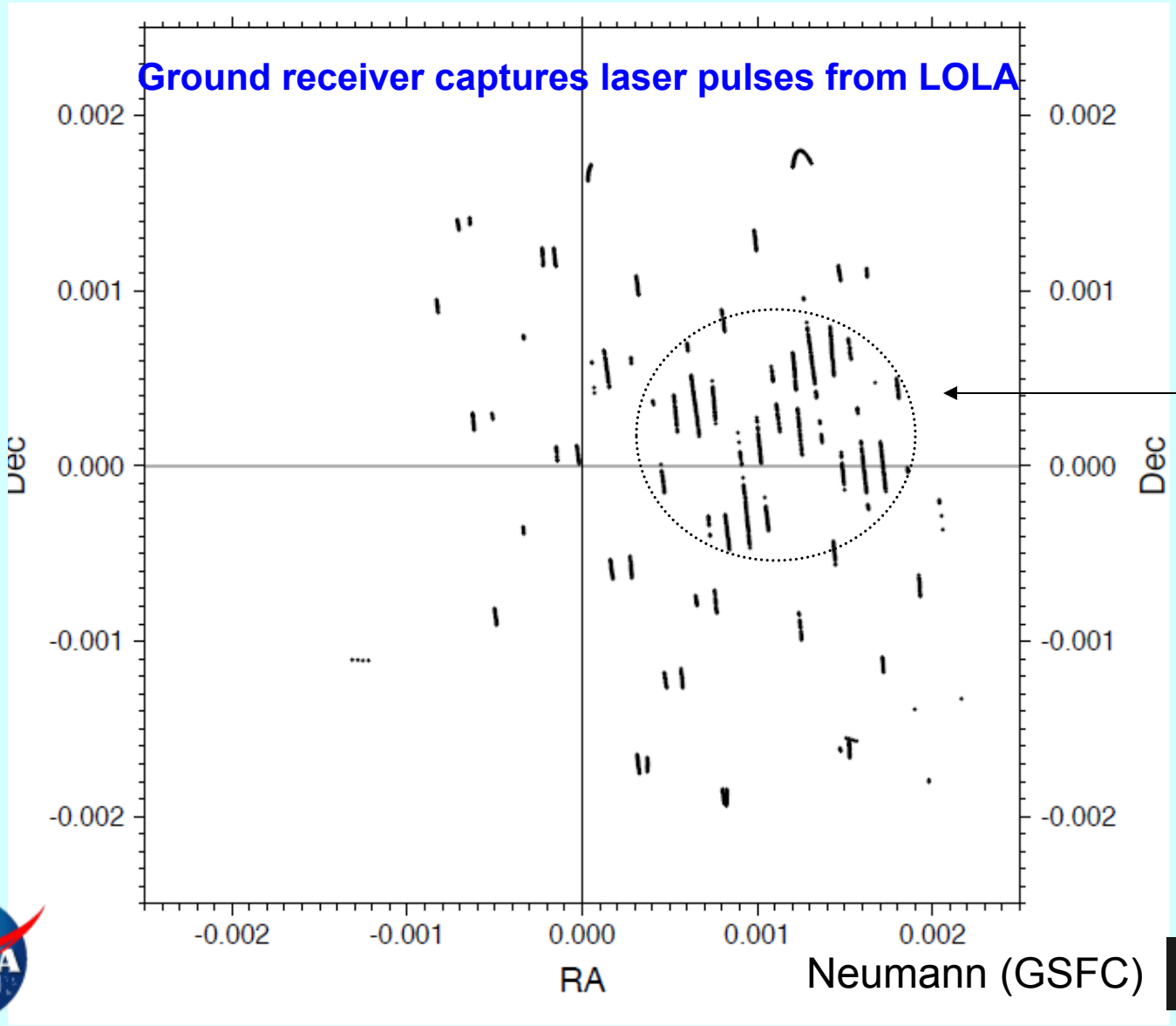


Colors represent
5 LOLA detectors

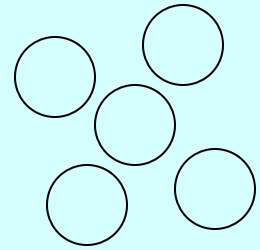
Neumann (GSFC)

LOLA 2-Way Ranging: Sep 13 2009

Plot of ground received events on LRO scan location



5 laser spots can be seen:



Neumann (GSFC)

Summary

• One-way (uplink only) laser transponders have now been proven to work operationally (currently going on 2 years of operations).

• Two-way asynchronous transponders have been successfully demonstrated at planetary distances.

• LRO-LR has been very successful thanks to support of ILRS.

• LRO will be moved from 50 km circular mission orbit to reduced maintenance elliptical orbit late in 2011. LR is expected to continue at least through FY12.

• More interesting science and technology is still to come from LRO-LR!

Transponder WG Meeting today at 17:00